Stereo Matching Technique using Belief Propagation

Annual Progress Seminar-II

By

Chitra Suresh

Under the Guidance of

Dr.Kushal R.Tuckley

Department of Electronics Engineering

Ramrao Adik Institute of Technology,

Nerul, Navi Mumbai

Outline

Motivation

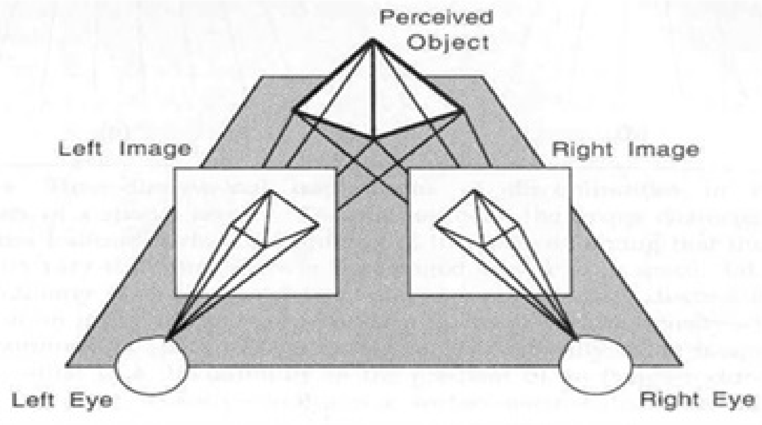
- Stereo matching is one of most active research topic concerning on the depth information processing capability
- Stereo matching quality is restricted due to real time processing capability,high computation and algorithm complexity
- It is difficult to predict high quality depth map because of image noise,Textureless regions,inconsistency and occlusions are inherent in captured images or video frames
- The depth map uncertainty can be solved by using global approach method
- Global approach can be formulated as an energy minimization problem of MRF,simultaneously considering labeling smoothness
- The graph cut and BP are two methods to optimize energy functions,research is directed towards optimize the BP algorithm

Introduction to Stereo matching

- Perception of space is created exclusively by human eyes and brain.
- The 3D experience comes from the left and right eye seeing slight different views .This effect is known as binocular vision.
- The perception of depth occur from disparity of a given 3D point in right and left retinal images.
- In binocular vision separate images from two eyes are successively combined into one 3D image in the brain.

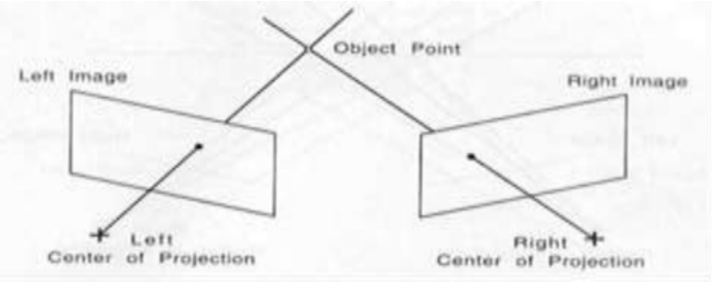
Introduction to Stereo matching

Conceptual diagram of Binocular vision



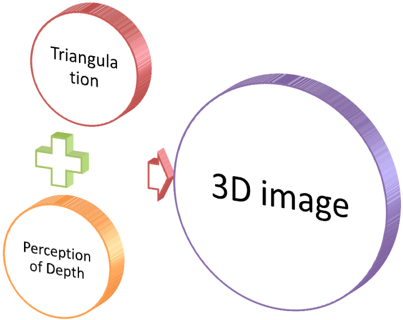
Introduction to Stereo matching

Conceptual diagram of triangulation



Introduction to Stereo matching

The method of finding depth from disparity is known as **triangulation**

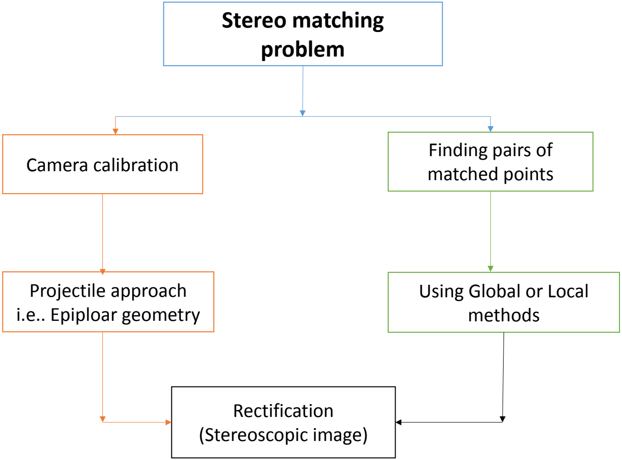


Formation of 3D image

Introduction to Stereo matching

- The disparity is difference in image location of the same 3D point for 3D image,when projected under two or more different cameras.
- The stereo image is captured by two cameras at two different view point of same scene or object.
- Two problems arises when finding disparity for stereo image.They are
  1. Use of prior knowledge or camera calibration
  2. Finding corresponding point in right image for each point in left image which known as **stereo vision problem ,stereo matching or stereo correspondence**.
- First problem can be solved by using projectile approach known as epipolar geometry which uses properties of rays rather than intrinsic parameters of camera.

Introduction to Stereo matching

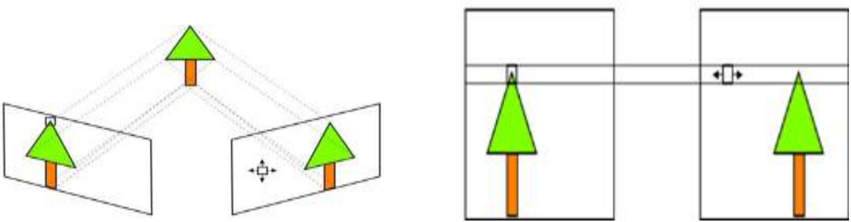


Introduction to Stereo matching

- The image rectification is to make the epipolar lines of two camera images aligned horizontally
- This may be accomplished by using linear transformations that rotate, translate and skew the camera images.
- After image rectification has been carried out, the epipolar lines of two projected points are parallel and horizontally aligned along the new image planes
- The stereo matching problem is therefore reduced to a one dimensional search along horizontal lines instead of a two dimensional search.

Introduction to Stereo matching

Camera images before rectification, after rectification



Camera image before rectification

Camera image after rectification

Figure: Camera images before and after rectification []

Introduction to Stereo matching

Disparity and Disparity map

- In stereo matching, the target is to find matching pixels of two given input images and the result saved as a disparity map
- The term disparity can be defined as horizontal distance between two matching pixels and the disparity map defines a value of this horizontal pixel distance for each image pixel coordinate
- disparity map is function of d(x, y) image pixel coordinates

Introduction to Stereo matching

In practice, depth maps are stored as gray scale images that show distance instead of texture. This means that an object located close to the camera turns out bright while a faraway located object looks darker (or vice versa). The relation between intensity and distance is specified as intensity range 0-255

Figure: 2D camera image and Depth map belonging to the image

Applications of Depth Map

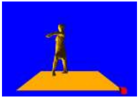
- View Interpolation can done using stereo pair and Depth map



Input Depth Map Novel view

- Image sequence analysis in entertainment,information transfer and for reconstruct 3D model sequences





Applications of Depth Map

- Used for robot navigation and depth information is used for object recognition to separate occluded image components

- Scientific applications such as extracts information from aerial surveys and for calculation of contour maps
- Gaze correction for video conferencing

Classification of Stereo matching Algorithm

- The stereo algorithms based on intensity profile are **Area-based and Feature- based algorithm**
- The constrains in area- based algorithm is to find the optimal size of the window
- The feature-based algorithms is restricted to using only specific feature,that only yield sparse disparity maps
- Global algorithm are based on baysian approach finds disparity as a energy minimization problem
- Global stereo algorithm are **Graph cut and belief propagation**

Literature Survey on major contribution in the field of stereo matching using MRF and BP

- Comparison of Graph cuts with Belief Propagation for stereo, Using Identical MRF Parameters[1]
    1. The disparity image can be achieved by modeling Markov Random Field and by using optimization algorithm such as Graph cut and Belief Propagation
    2. The solutions produced by Graph cut are smoother while accelerated Belief Propagation algorithm was faster.
- Efficient Belief Propagation for Early Vision:
    1. Technique used is difference between two labels rather than on particular pair of labels
    2. Modified message update scheme where nodes are split into two Messages and updated alternately.

Literature Survey on major contribution in the field of stereo matching using MRF BP

- Low Memory Cost Block Based Belief Propagation for Stereo Correspondence
  1. Block based BP algorithm directly partitions image into separated independent blocks, convergence criteria is important for each block.
  2. The convergence is according to equivalence of all disparities for each node in a block over successive iterations
- Hardware-Efficient Belief Propagation
  1. MRF is divided into multiple regions known as tile and iterations are done on those regions.
  2. Robust function is used as smoothness cost.

summary of literature survey

Year.	Method	Further study
[2003]	Comparative study of Graph cut,BP	Improving formulation MRF
[2004]	Different MUS of BP	MUS schemes for other cost functions
[2007]	2D BP Graph is divided into blocks	processing of finished block and unfinished block
[2009]	Tile based BP Fast message construction	Tile based scheme can be studied for different smoothness cost functions

Research Methodology

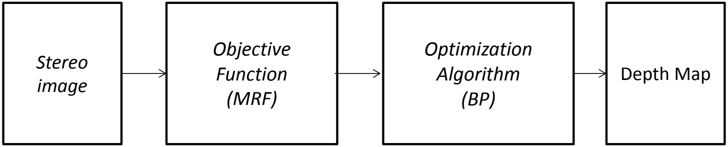


Figure: Block diagram for stereo algorithm

Research Methodology

- The stereo images are known as stereo pairs have been rectified such that each pixel row on the left image perfectly corresponds to the right.
- The objective function is Markov Random Field (MRF)formulation which is a powerful tool and effective probabilistic model
- MRF are undirected graphical models that can encode spatial dependencies.
- The cost associated with the matching pixel to the corresponding pixel in the other stereo image at that disparity value is known as a Datacost
- Datacost is based on the intensity differences between the two pixels,The Sum of Absolute Difference(ABS) or Sum Of Square Difference(SSD) functions are used as Datacost

Research Methodology

- A MRF approach uses second compatibility function which expresses compatibility between neighboring variables.
- A pair-wise Markov Random Field are used for stereo problems because each variable is able to influence every other variable in the field through pair -wise connections
- A pair-wise compatibility function is known as smoothnesscost function.
- The MRF is defined in terms of energy function rather than compatibility functions which is based on Birchfield-Tomasi matching cost
- The cost is converted into compatibility by calculating $\exp^{-c}$.

Research Methodology

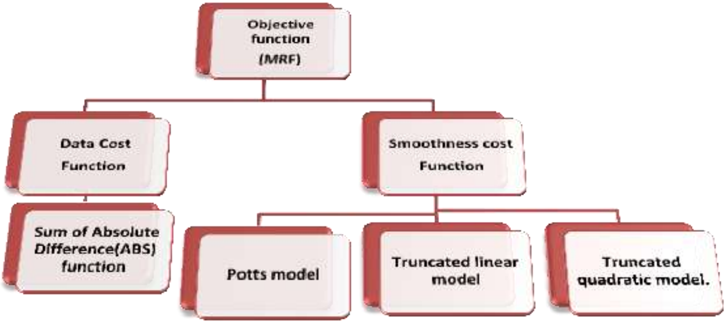
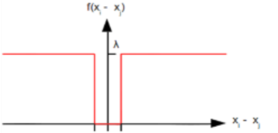
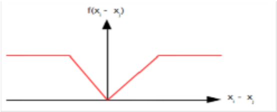


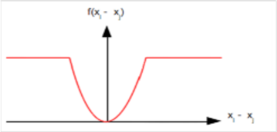
Figure: Flow chart for objective function

Research Methodology(Smoothnesscost funtions)





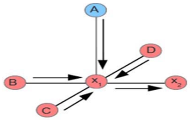
Truncated linear model $f(n) = \lambda \times \min(|n|, K)$



Truncated quadratic model. $f(n) = \lambda \times \min(n^2, K)$

Research Methodology

- The belief propagation algorithm was proposed by Pearl in 1988 for finding exact marginal on graphs that contain no loops or cycles,It can be applicable to the graphs which contain loops
- The loopy belief propagation (LBP) algorithm is approximate inference algorithm which passes the messages around network until stable belief state is reached.
- A node passes a message to an adjacent node only when it has received all incoming messages, excluding the message from the destination node to itself



Research Methodology

There are two steps in LBP iterative inference algorithm

1. Message update :There are three methods to message update, any one is used for message update
    1. Sum-Product : Sum of probabilities calculated, for each label normalized and maximum is taken
    2. Max- Product: Label of Max probability is taken.
    3. Min-Sum: the cost is considered and min cost is taken
2. Calculating Belief ,using messages obtained by message updates and energy functions

Research Methodology

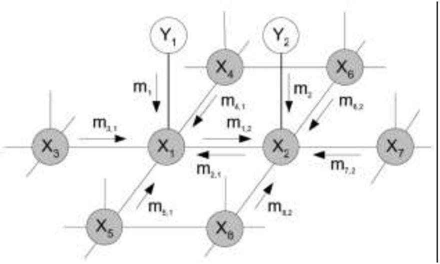


Figure: Message passing in max product LBP

Research Methodology

- In Message passing in max product LBP diagram white nodes are observable variable which is is the right image intensity values
- Gray nodes are hidden variable which is shift values or labels(initial disparity map)
- In max product algorithm,the new message sent from node x_2,For t iterations,Message update
- $m_{1,2}^{new} \leftarrow max_{x1} \psi(x_1, x_2) m_1 m_{3,1} m_{4,1} m_{5,1}$
- where as

$\psi(x_1, x_2)$ is compatibility matrix between node $x_1 x_2$
m_1 is local evidence from node y_1
$m_{3,1} m_{4,1} m_{5,1}$ are neighboring evidence from shift values or labels

- The belief at node x_1 is computed as
- $b_1 \leftarrow K m_1 m_{2,1} m_{3,1} m_{4,1} m_{5,1}$
  - K is Normalization constant
  - The product of two messages is component wise product
- The computational complexity of Max product LBP algorithm is $O(TNL^2)$

  Where

  T is number of iterations

  N is number of pixels

  Lis number of discrete states or label

MRF Implementation

- Data cost is associated with the matching pixel to the corresponding pixel in the other stereo image at that disparity value
-
$$Datacost = \sum_{x,y} |I_{x,y} - J_{x+label,y}| \tag{1}$$

  $I_{x,y}$ Pixel intensity values of Left Image

  $J_{x,y}$ Pixel intensity values of Right Image

  Label or Disparity=16

MRF Implementation

- Smoothness cost or a pair-wise Markov Random Field in which each variable is able to influence every other variable in the field through pair -wise connections.
- Truncated linear model used as smoothness cost function
- $$Smoothnesscost = \lambda \times (|n|, K) \tag{2}$$

  λ is tunable variable

  K is Truncation value that decides maximun penalty

MRF Implementation

- 4-connected neighborhood is considered for Smoothness cost
- $$Smoothnesscost = \sum_{neighborsofp,q} f\{min(|d_p - d_q|), 2\} \tag{3}$$
  - Truncated linear mode is used as Smoothness cost
  - d_p is pixel intensity values from left image i.e.Reference image
  - d_q is Summation of 4-connected neighbors from right image i.e.Disparity image
- Energy function =Datacost function + Smoothnesscost function

MRF Implementation

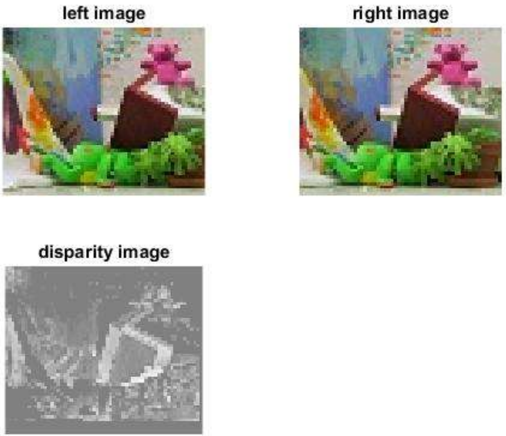


Figure: For Tedy stereo pair and its disparity using MRF energy functions

MRF Implementation

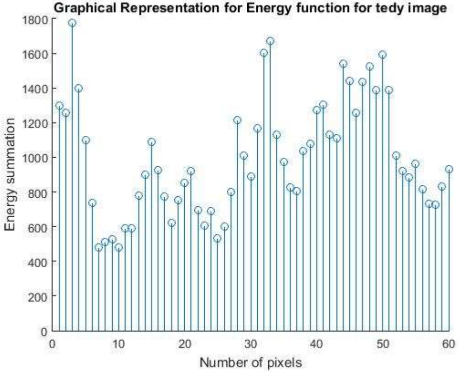


Figure: For Tedy stereo pair and its disparity using MRF energy functions

MRF Implementation

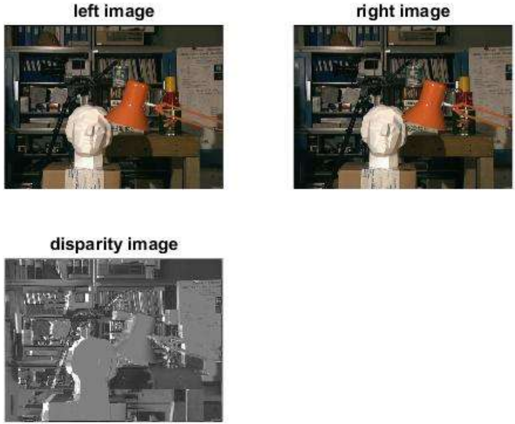


Figure: For Tsuba stereo pair and its disparity using MRF energy functions

MRF Implementation

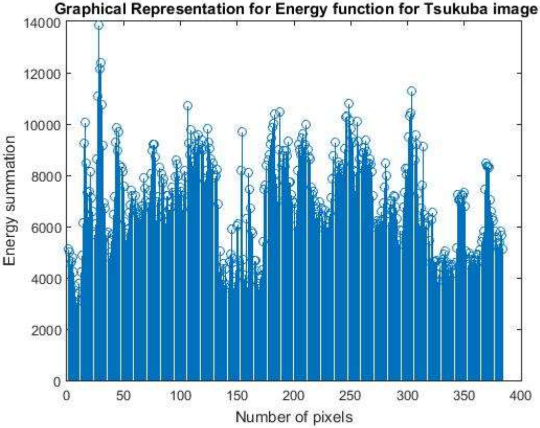


Figure: For Tsuba stereo pair and its disparity using MRF energy functions

Conclusion

- The terms and concepts related to Markov Random Field (MRF)formulation and Message updates in iterative inference belief propagation are studied.
- Literature survey on major contribution in the field of stereo matching using Markov Random field and inference algorithm like Belief Propagation are studied and to find gap analysis for further research
- Implemented Markov Random Field (MRF)energy functions like Data cost using Sum of Absolute Difference(abs)and smoothness cost function using Truncated linear model.

Future work

1. Implementation of Maxproduct Belief Propagation algorithm on MRF formation for linear smoothnesscost function
   - The parameters considered for Maxproduct BP are **number of iterations** and **disparity level or label**
2. Implementation of Maxproduct Belief Propagation algorithm on MRF formation for quadratic smoothnesscost function

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Thank You...